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Sanitary Sewer Overflows and Emergency Room Visits for Gastrointestinal Illness: Analysis of Massachusetts Data, 2006–2007

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Background: Sanitary sewer overflows (SSOs) occur when untreated sewage is discharged into water sources before reaching the treatment facility, potentially contaminating the water source with gastrointestinal pathogens.

Objectives: The objective of this paper is to assess associations between SSO events and rates of gastrointestinal (GI) illness in Massachusetts.

Methods: A case-crossover study design was used to investigate association between SSO events and emergency room (ER) visits with a primary diagnosis of gastrointestinal (GI) illness in Massachusetts for 2006–2007. ER visits for GI were considered exposed if an SSO event occurred in the county of residence within three hazard periods, 0–4 d, 5–9 d, or 10–14 d, before the visit. A time-stratified bidirectional design was used to select control days for each ER visit on the same day of the week during the same month. Fixed effect logistic regression models were used to estimate the risk of ER visits following the SSO event.

Results: During the study period, there were 270 SSO events for northeastern Massachusetts and 66,460 ER admissions with GI illness listed as the primary diagnostic code. The overall odds ratio (OR) for ER visits for GI illness was 1.09 [95% confidence interval (CI): 1.03, 1.16] in the 10–14 d period following an SSO event, with positive ORs for all age groups and for three of the four counties. The 0–4 d and 5–9 d periods following an SSO event were not associated with ER visits for GI illness overall, and associations by county or age were inconsistent.

Conclusions: We demonstrated an association between SSO events and ER visits for GI illness using a case-crossover study design. In light of the aging water infrastructure in the United States and the expected increase in heavy rainfall events, our findings suggest a potential health impact associated with sewage overflows. https://doi.org/10.1289/EHP2048

Introduction

Water infrastructure in the United States is aging, and many, older cities in the United States have infrastructure that needs to be upgraded. The U.S. Environmental Protection Agency (EPA) estimates that the majority of the nation's sewage collection infrastructure is between 30 and 100 y old, putting it at risk for leaks, blockages, and malfunctions due to deterioration (U.S. EPA 2000). This aging water infrastructure is vulnerable to changes in weather that are expected to occur with climate change (Patz et al. 2005, 2008). In particular, the expected changes in precipitation events and increases in heavy rainfall events can have negative impacts on water infrastructure. Heavy rainfall events can overwhelm these systems, causing untreated waters and sewage to be released into receiving waters. Two studies conducted in Massachusetts reported associations between flood events and emergency room (ER) visits for gastrointestinal (GI) illness and specifically for outpatient visits associated with *Clostridium difficile* infection (Lin et al. 2015; Wade et al. 2014). Other studies focusing on specific infrastructure concerns have demonstrated that combined sewer overflow (CSO) events may be associated with increased GI illness. A study in Massachusetts found that CSO releases into drinking water sources were associated with higher rates of ER visits for GI illness following heavy rainfall events (Jagai et al. 2015). Another study, conducted in New Jersey, estimated the probability of acquiring GI illness from accidental ingestion of water contaminated by CSO outfalls was 0.70 over the course of a year for people who recreated in the affected waters (Donovan et al. 2008).

Sanitary sewer systems, which, unlike combined sewer systems, have separate networks for sewage and storm water, are still vulnerable to excess precipitation. According to the U.S. EPA, there are approximately 19,500 sewer systems nationwide designed to handle an average daily flow of roughly 50 billion gallons of raw sewage (U.S. EPA 2000). Sanitary sewer overflows (SSOs) occur when untreated sewage is discharged into the environment from the sanitary sewer system before reaching sewage treatment facilities; they are more likely to occur as a result of aging water infrastructure (U.S. EPA 2016a). SSOs can occur for a variety of reasons, including, but not limited to, severe weather, blockages and breaks in the sewer lines, improper system operation and maintenance, and vandalism (U.S. EPA 2016a). These events are a concern because raw sewage containing pathogens is discharged directly into the environment. The magnitude of SSO events can vary greatly, ranging from small events affecting just one household, such as basement flooding, to events affecting several street blocks. The potential for exposure can, therefore, range from a few people having direct contact with raw sewage (in the smaller events) to directly affecting drinking water and recreational water sources (in the larger events). Currently, the U.S. EPA estimates that 23,000–75,000 SSO events, not including those that back up into individual buildings (i.e., into basements), occur each year (U.S. EPA 2016a). In 1995, the U.S. EPA identified 1,103 large (i.e., those producing more than 10 million gallons of wastewater) sanitary sewer systems with untreated sewage overflows that required corrective action by the end of 2016. Regulatory action includes assessment and, where appropriate, a civil judicial complaint, an enforceable federal or state enforcement order, or permit requirements met (appropriate permits obtained) that address the noncompliance. At the end of 2015, 914 systems had complied with required corrective action, and 83 had initiated enforcement actions (U.S. EPA 2016b).

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SSO reporting requirements vary from state to state. Several states, including California, Texas, and Massachusetts, have passed laws mandating the reporting of SSOs, whereas events are underreported in other states (U.S. EPA 2000). Based on a sample of news reports from 2000, there were at least 59 SSO events in 18 states that resulted in the release of an estimated 1.2 billion gallons of sewage (U.S. EPA 2000). Of those reported, the most significant was a release into Florida's Indian River of approximately 72 million gallons of raw sewage that resulted in drinking water advisories and beach closures throughout most of the state (U.S. EPA 2000).

These SSO events can contaminate water sources with pathogenic microorganisms associated with untreated sewage, including protozoa (e.g., *Cryptosporidium sp.*), viruses (e.g., norovirus, adenovirus), and bacteria (e.g., *Salmonella sp.*) (Donovan et al. 2008; Gerba 2000; Levin et al. 2002; Marsalek and Rochfort 2004). Infection with these pathogens can cause gastroenteritis (i.e., diarrhea, nausea, or vomiting) and upper respiratory infections. When SSO events contaminate public places and waters, people can be at risk of exposure to the untreated sewage when recreating in open waters, drinking from a contaminated water supply, coming in contact with contaminated flood waters, or eating contaminated fish or shellfish. In September 2000, residents of Springfield, Missouri, and neighboring communities were issued drinking-water alerts after a million-gallon SSO event into Goodwin Hollow Creek, an underground stream that fed several springs and that was the source for private water wells (U.S. EPA 2000).

To our knowledge, no studies have quantified the health risk associated with SSO events in the United States. The goal of this study was to estimate associations between SSO events and gastrointestinal illness in Massachusetts. We used data on SSO events for 2006–2007 from the eastern region of Massachusetts and emergency room (ER) visits for GI illnesses to estimate associations. The aims were to determine if there was a positive association between SSO events and ER visits for GI illness and to evaluate potential variation among subpopulations and geographic areas.

Methods

Emergency Room Visits

ER visits for gastrointestinal illness were collected from the State of Massachusetts Division of Health Care Finance and Policy, Executive Office of Health and Human Services (http://www.chiamass.gov/), from 1 January 2006 to 31 December 2007, as described previously (Lin et al. 2015; Wade et al. 2014; Jagai et al. 2015). Patient-level information available in the Massachusetts ER database included town and residential zip code, age, gender, primary diagnosis code, and five associated secondary diagnosis codes. The diagnoses were coded according to the *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM; Centers for Disease Control and Prevention 2013). Visits to the ER for GI illness were restricted to those with a primary diagnosis of ICD9-CM 001-009, 558.9, 787, 787.0, 787.4, 787.9, or 787.91. This list includes bacterial, viral, and protozoal pathogens that have incubation periods ranging from <1 d to 14 d. We excluded *a priori* ER visits with a diagnosis of *Clostridium difficile* (008.45) because it is primarily considered a hospital-acquired infection (Lin et al. 2015; Wade et al. 2014; Bouza 2012). In addition, annual rates of ER visits for GI illness were calculated for all locations and by county per 1,000 population using county-level intercensal population estimates for the years 2006 and 2007 (U.S. Census Bureau 2011). Average annual rates for the two years were also calculated.

The ER data obtained did not contain any personally identifying information and was collected by the state of Massachusetts for administrative purposes. Therefore, informed consent was not necessary, and the use of administrative data was determined to be exempt from Institutional Review Board review (Wade et al. 2014).

Sanitary Sewer Overflows

Information on sanitary sewer overflow (SSO) events was obtained from the Massachusetts Department of Environmental Protection (https://www.mass.gov/orgs/massachusetts-department-of-environmental-protection). The state of Massachusetts requires all SSO events to be reported immediately by wastewater facility operators via telephone, email, or both, and a written report is to be submitted within 5 d. This database includes information such as the date and location (town and county) of the SSO event. The main cause of the SSO (e.g., heavy rainfall, infrastructure failure) was also documented. Complete SSO event data were only available for four counties in the northeastern region of Massachusetts: Essex, Middlesex, Norfolk, and Suffolk. SSO events occurring between 1 December 2005 and 31 January 2008 were included in the analysis (Figure 1). Data for previous years were not available in electronic format and therefore were not accessible for this analysis.

Statistical Analyses

In this analysis, we used a case-crossover approach to evaluate the association between SSO events and ER visits due to GI illness stratified by either county (the four counties with available SSO data: Essex, Middlesex, Norfolk, and Suffolk) or by age category. Age categories included <5 y of age, 6–19 y of age, 20–64 y of age, and >65 y of age. A case-crossover design is useful when an exposure is transient, such as an SSO event. The study is self-matched, with each case serving as its own control. In the case-crossover design, cases serve as their own controls at a different time period before or after the disease event. Occurrence of the exposure during a predefined hazard period (the time interval before the event when the exposure is believed to cause the event) is compared by case and control status (Maclure 1991; Maclure and Mittleman 2000). For our analysis, cases are dates of ER visits for GI illness, and controls are dates selected before and/or after the case date. Individual characteristics, such as gender, race, and comorbid conditions, do not need to be controlled for in the analysis because the study design itself accounts for these variants in the population (Wade et al. 2014; Maclure 1991; Maclure and Mittleman 2000). It was hypothesized that GI illness could have occurred 0–14 d following an SSO event, representing the lag between sewage discharge and exposure and symptoms (incubation period) (Lin et al. 2015; Wade et al. 2014; Jagai et al. 2015). We divided

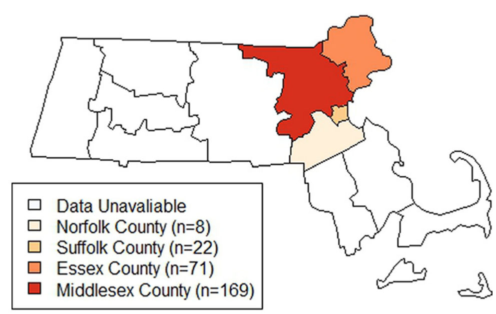

Figure 1. Number of sanitary sewer overflow (SSO) events in eastern Massachusetts by county, 2006–2007. Data from the Massachusetts Department of Environmental Protection.

this time window into three mutually exclusive categories: 0–4 d, 5–9 d, and 10–14 d. We hypothesized that ER visits occurring shortly after the SSO event (0–4 d) would most likely be due to direct contact with the raw sewage, whereas ER visits farther away in time from the SSO event (5–9 d and 10–14 d) would most likely be associated with indirect exposure resulting from drinking from a sewage-contaminated supply following the overflow event.

ER visits occurring outside of Essex, Middlesex, Norfolk, and Suffolk Counties in Massachusetts were excluded. In this analysis, we used a time-stratified referent selection process (Wade et al. 2014), which is subject to very little bias due to seasonal variation or other time trends (Janes et al. 2005). To choose controls, the entire study period (1 December 2005–31 January 2008) was divided into 26 total months. Control dates were selected two weeks before and/or two weeks after the case ER admission date. Depending on when the admission date occurred, each case date had one or two control dates within the same month. In addition, control dates were matched by day of the week to account for any variability in care-seeking behavior based on the day of the week. Exposure to an SSO event was determined if the case ER admission date or if the control date(s) was within 0–4 d, 5–9 d, or 10–14 d following an SSO event. SSO events from the last month in 2005 (December) and the first month in 2008 (January) were included in the analysis to assign exposure associated with case and/or control hazard periods corresponding to ER visits in early 2006 and late 2007. In addition, we addressed seasonal factors such as temperature and seasonal variations in gastrointestinal illness by matching cases and controls within a narrow time frame (1 mo).

The data were analyzed using a fixed effect conditional logistic model (Lin et al. 2015; Wade et al. 2014). Separate conditional models for each county and by age category were run, and the results were qualitatively assessed for marked differences by county and by age group.

Sensitivity Analyses

Because it is hypothesized that severe rain events are expected to increase in the future (U.S. EPA 2014), thus contributing to potentially more SSO events, we subset the data and reran the analyses using only SSO events caused by heavy rainfall. We also considered a less-restricted definition of a GI-illness ER visit. Rather than only considering cases with a primary diagnosis of GI illness (see above, "Emergency Room Visits"), we expanded the definition to include at least the primary diagnosis or any of the five associated secondary diagnostic codes available in the Massachusetts ER database (http://www.chiamass.gov/).

All data were analyzed using Stata v.13 (StataCorp LLC), and conditional logistic regression was performed using the xtlogit command. Graphics were created using R version 3.1.2 (R Project for Statistical Computing) using the ggplot2 package (Wickham 2009).

Results

From 1 December 2005 to 31 January 2008, 270 SSO events were recorded by the Massachusetts Department of Environmental Protection for the northeastern region of Massachusetts. SSO events were the most frequent in Middlesex ($n = 169$) and Essex ($n = 71$) Counties (Table 1). During the study period, there were 66,460 ER admissions with GI illness listed as the primary diagnostic code, representing a rate of 9.4 per 1,000 population. Overall, the highest counts of ER admissions for GI illness were in Middlesex ($n = 23,355$) and Suffolk ($n = 17,125$) Counties, representing average annual rates of 8.0 and 12.4 per 1,000 population, respectively.

Table 1. Sanitary sewer overflow events and emergency room visits for gastrointestinal illness in northeastern Massachusetts, overall and by county, for 2006 and 2007, primary diagnosis only.

	All counties			Middlesex			Essex			Suffolk			Norfolk		
Time period	No. ER visits[a]	Population[b]	Annual rate[c]	No. ER visits[a]	Population[b]	Annual rate[c]	No. ER visits[a]	Population[b]	Annual rate[c]	No. ER visits[a]	Population[b]	Annual rate[c]	No. ER visits[a]	Population[b]	Annual rate[c]
2006	31,941	2,873,175	11.12	11,678	1,456,528	8.02	7,677	729,455	10.52	7,960	687,192	11.58	4,626	653,421	7.08
2007	34,519	2,887,138	11.96	11,677	1,463,106	7.98	8,687	730,664	11.89	9,165	693,368	13.22	4,990	656,582	7.60
Average			11.54			8.00			11.21			12.40			7.34
2006	9,187	167,408	54.88	2,997	84,727	35.37	2,245	44,248	50.74	2,651	38,433	68.98	1,294	38,415	33.68
2007	10,077	166,428	60.55	3,135	84,162	37.25	2,614	43,768	59.72	3,063	38,498	79.56	1,265	38,069	33.23
Average			57.71			36.31			55.23			74.27			33.46
2006	9,654	547,071	8.67	3,053	275,544	5.69	2,473	151,353	7.85	2,596	120,174	10.19	1,532	129,530	5.88
2007	4,742	546,399	8.99	1,567	275,776	5.39	1,188	150,329	8.55	1,225	120,294	11.40	762	129,814	5.93
Average			8.83			5.54			8.20			10.80			5.91
2006	15,262	1,801,286	8.47	5,982	909,768	6.58	3,511	434,973	8.07	3,633	456,545	7.96	2,136	393,530	5.43
2007	16,389	1,813,942	9.04	5,895	915,033	6.44	3,898	436,740	8.93	4,176	462,169	9.04	2,420	395,859	6.11
Average			8.75			6.51			8.50			8.50			5.77
2006	2,750	357,410	7.69	1,132	186,489	6.07	733	98,881	7.41	451	72,040	6.26	434	91,946	4.72
2007	3,141	360,369	8.72	1,161	188,135	6.17	890	99,827	8.92	555	72,407	7.67	535	92,840	5.76
Average			8.21			6.12			8.16			6.96			5.24

Note: ER, emergency room.
[a]*International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD9-CM): 001-009, 558.9, 787, 787.0, 787.4, 787.9, or 787.91.
[b]County-level intercensal population estimates.
[c]Per 1,000 population.

The highest average annual rates were seen in the youngest age category of 0–5 y, with 74.3 and 55.2 per 1,000 population in Suffolk and Essex Counties, respectively.

The combined odds ratios (ORs) for ER visits for GI illness were 0.97 (95% CI: 0.91, 1.03) and 1.01 (95% CI: 0.95, 1.07) in the 0–4 and 5–9 d periods following an SSO event, respectively (Figure 2). However, in the 10–14 d following an SSO event, there was evidence of increased ER visits for GI illness, with a combined OR = 1.09 (95% CI: 1.03, 1.16). Considering county-stratified results, the 0–4 d hazard period following an SSO event showed consistently negative, though insignificant, odds ratios, whereas the results were highly variable for the 5–9 d period following an SSO event. The odd ratios for the 10–14 d hazard period after an SSO event were generally increased, with the strongest associations observed in Suffolk County (Figure 2). The results also varied by age category (Figure 3). The 0–4 d hazard period following an SSO event showed consistently negative, though insignificant, odds ratios for all age groups. The 5–9 d hazard period showed inverse associations for the younger age categories and increased odd ratios for the 20–64 y and >65 y age categories. The strongest associations were again observed in the 10–14 d hazard period following an SSO event for all age groups, and the strongest association was observed in those between 6 and 19 y of age, although the association was imprecise and had a large confidence interval (Figure 3).

For sensitivity analyses, we considered ER visits for which GI illness was the primary diagnosis or for which any of 5 associated secondary diagnosis codes included GI illness (see Table S1). The number of admissions increased to 104,322; however, the patterns of association were similar. The combined odds ratios for ER visits for GI illness were 0.97 (95% CI: 0.92, 1.01) and 1.02 (95% CI: 0.97, 1.07) in the 0–4 and 5–9 d periods following an SSO event, respectively (see Figure S1). The strongest associations were seen in the 10–14 d hazard period when considering all counties [OR = 1.05 (95% CI: 1.00, 1.11)] and again in Suffolk County [OR = 1.15 (95% CI: 1.06, 1.24)] specifically (see Figure S1). Similar to the primary diagnosis–only analysis, the associations were slightly elevated in those 6–19 y old [OR = 1.15 (95% CI: 1.00, 1.34)] (see Figure S2). In the analysis of SSOs driven by heavy rainfall only, which included a total of 131 events, the 0–4 and 5–9 d periods following an SSO event showed inverse associations: OR = 0.92 (95% CI: 0.85, 0.99) and OR = 0.86 (95% CI: 0.80, 0.93), respectively (results not shown). However, there was a positive association in the 10–14 d hazard period following an SSO event for all counties [OR = 1.04 (95% CI: 0.96, 1.12)], but the association was attenuated compared with all SSO events (results not shown).

Discussion

In the four eastern Massachusetts counties included in our analysis, an ER visit for GI illness was more likely 10–14 d after a sanitary sewer overflow event than 10–14 d after a day without an SSO event. In contrast, ER visits for GI illness did not appear to be associated with SSO events 0–4 d or 5–9 d before the ER visit. Our findings suggest that SSO events may be associated with ER visits for GI illness. SSO events could introduce pathogenic microorganisms that cause gastrointestinal illness into the environment, where people may come into contact with them through drinking water, recreational water, contaminated soil, or other transmission routes. Previous studies have suggested that overflow events can contaminate water sources because they contain fecal matter and pathogens, which can contaminate water supplies, soil, and other environments with pathogens that cause gastrointestinal illness (Donovan et al. 2008; Gerba 2000; Levin et al. 2002; Marsalek and Rochfort 2004). However, our study is

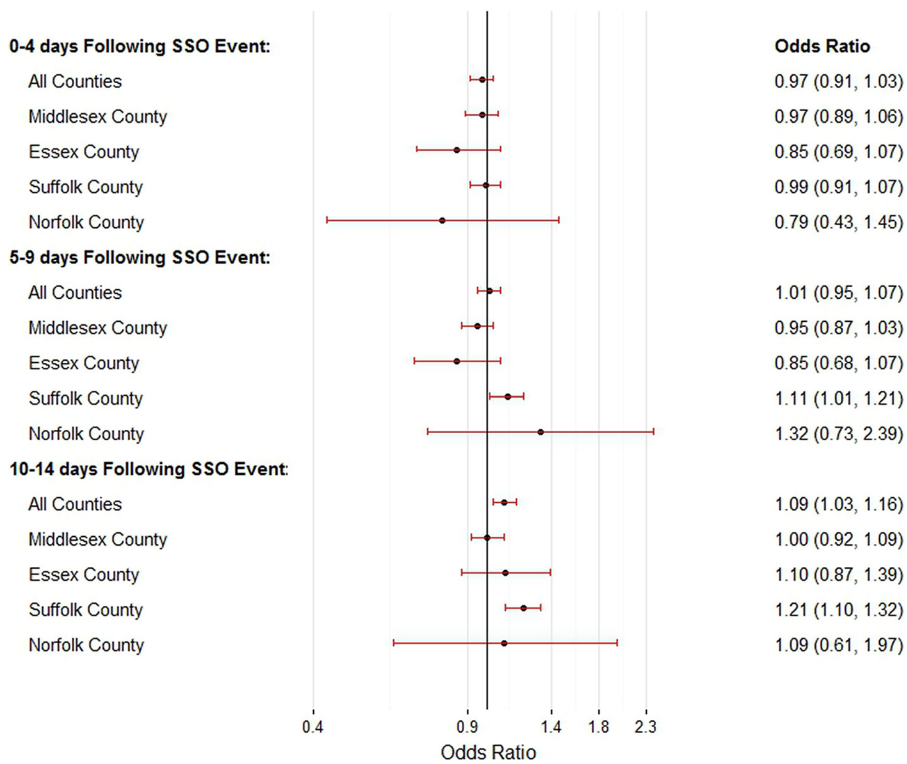

Figure 2. Odds ratios and 95% confidence intervals calculated using a conditional logistic regression model for a time-stratified case-crossover analysis for emergency room visits with primary diagnosis of gastrointestinal illness [*International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD9-CM): 001-009, 558.9, 787, 787.0, 787.4, 787.9, or 787.91] in the 0–4 d, 5–9 d, and 10–14 d period following a sanitary sewer overflow (SSO) event for all counties and by county, 2006–2007.

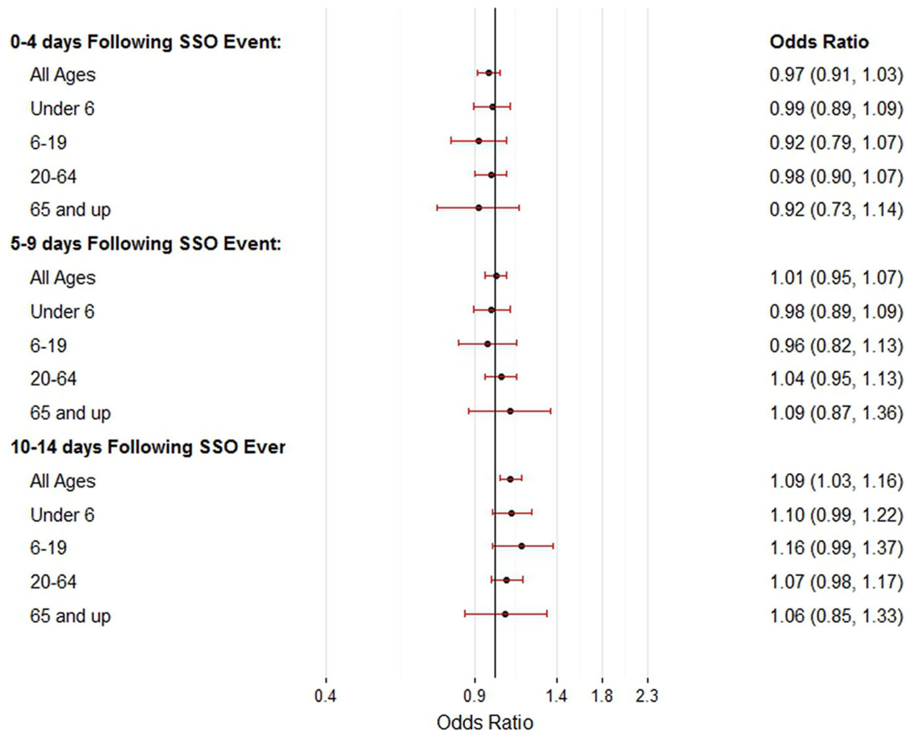

Figure 3. Odds ratios and 95% confidence intervals calculated using a conditional logistic regression model for a time-stratified case-crossover analysis for emergency room visits with primary diagnosis of gastrointestinal illness [*International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD9-CM): 001-009, 558.9, 787, 787.0, 787.4, 787.9, or 787.91] in the 0–4 d, 5–9 d, and 10–14 d period following a sanitary sewer overflow event for all ages and by age category, 2006–2007.

the first that we know of to demonstrate an association between SSO events and GI illness.

Although the impact of SSO events on health outcomes has not been previously studied, there have been a few studies that have considered the impact of combined sewer overflows (CSOs) on enteric infections in humans. A study in Massachusetts found that areas with CSOs discharging to drinking-water sources had higher rates of ER visits for GI illness following heavy rainfall events (Jagai et al. 2015). Using a human health risk assessment methodology, another study estimated that the probability of acquiring GI illness from incidental ingestion of water contaminated by CSO outfalls was 70% over the course of a year for those who recreated in the contaminated waters (Donovan et al. 2008). Two Wisconsin studies of pediatric ER visits for diarrheal illness reported an increase following sewage bypass events for those whose drinking-water supply was sourced from Lake Michigan (Drayna et al. 2010; Redman et al. 2007). Although SSO events are generally smaller than CSO events in terms of volume discharged, they are nevertheless a significant concern because they are not regulated in the same way as CSO events. Combined sewer overflow systems are permitted through the U.S. EPA National Pollutant Discharge Elimination System (NPDES) because overflows are expected, and all overflow events are to be reported through this system. However, laws for reporting SSO events vary from state to state, and many states do not have any reporting requirements. In Massachusetts, the reporting of SSO events is required; therefore, we believe the database to be complete. Although the data on the volume of the overflow may be estimated, the date and location of the SSO event, which were used in our analysis, are accurate.

One advantage of our study is the use of the case-crossover design, which controls for nonvarying individual factors (i.e., sex and race). This study design also controls for factors that are not likely to vary over the 28 d between the case and referent periods (i.e., age, comorbid conditions, and other factors). In addition, this study design is advantageous because time trends and day-to-day variations in behavior (e.g., people are less likely to go to the ER on weekends) are also controlled for through time stratification and matching by day of the week. Because we did not have access to personally identifying information, we could not rule out the possibility that some individuals may have visited the ER for GI illness on multiple occasions. Although we expect multiple visits by the same individual to be rare, this is a limitation that could affect our estimates in a direction that is difficult to predict.

Although the association estimated in our study ($OR = 1.09$ at 10–14 d) is small in magnitude, it suggests a potential preventable large public health impact at the population level. The use of ER data is a limitation of this study because it is influenced by factors such as access to emergency care facilities and the severity of the illness. Moreover, the majority of GI illnesses do not result in ER visits (Craun et al. 2010; Schuster et al. 2005; Yoder et al. 2008), and those that do result in ER visits may not be representative of the broader occurrence of GI illness in the population.

The association between increased ER visits and SSO events was only observed in the 10–14 d period following the SSO event. This may be due to delayed exposure to pathogens in the environment (e.g., in contaminated flood waters), illness caused by pathogens with longer incubation periods (such as protozoa), a delay in the time from the onset of illness to an ER visit, or a combination of these factors. Previous studies of drinking water turbidity and GI illness have concluded that lag structures with a mean of 7–8 d were the most appropriate for the estimation of lagged effects (Egorov et al. 2003; Naumova and Macneill 2008). In the 10–14 d period following an SSO event, associations were elevated for each age group, and although estimates were slightly stronger in the 6–19 y age group, the 95% confidence bounds overlapped considerably with the estimates for the other age groups.

We observed variations in associations between SSO events and ER visits for GI illness across the counties considered, with the strongest associations occurring in Suffolk County. The counties we considered in our analysis differed in several ways that could affect the association between SSO events and ER visits for GI illness, including service provider, age and maintenance of infrastructure, size of population, and size of county. Differences in risk factors for GI infections among counties, such as drinking-water source (ground, surface, or mixed) and septic tank density, may contribute to differences in associations between SSO events and ER visits among counties (Cohen et al. 2008; Naumova et al. 2000). Differences in these factors among counties may explain the variation in the associations between SSO events and ER visits for GI illness we demonstrate by county. Future work on the health impact of SSO events should include outpatient visits for GI illness and should also consider variations in the communities, the severity of the SSO event, and the potential pathway of exposure.

With climate change, it is predicted that extreme rainfall events will increase, thereby increasing the possibility of SSO events. It is estimated that single-day heavy rainfall events are expected to increase, particularity in the northeastern United States (U.S. EPA 2014; Spierre and Wake 2010). The increase in intensity of precipitation events will likely cause more SSO events because the infrastructure is not designed to handle large volumes of water. Our study provides evidence that SSO events may be associated with increased risk of ER visits for gastrointestinal illness. Our findings are the first that we know of to demonstrate this association and require confirmation; however, they support the need for additional research to evaluate potential health impacts of SSOs and to determine appropriate public health responses.

Conclusion

We observed an association between SSO events and emergency room visits for GI illness. The overall OR for ER visits for GI illness was 1.09 (95% CI: 1.03, 1.16) in the 10–14 d period following an SSO event. In light of the aging water infrastructure in the United States and the expected increase in heavy rainfall events, our findings suggest a potential health impact associated with sewage overflows and a need for increased study of the health impacts of sewer overflow events.

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